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Discussion paper

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Abstract

This paper analyzes the claim, made by both academics and by industry insiders, that vessels speed up under conditions of high freight rates and low bunker prices. The rationale for the claim is that a ship should move slowly when high bunker prices make energy cost savings great and when the low freight rates give little temptation to rush for the next transport job. The analysis is based on the theoretical model for speed optimization by Ronen (1982) applied to AIS¹ data on actual speeds of all VLCCs² leaving from the Persian Gulf to main destinations in Japan, South Korea, China from 2006 to 2012. We find some support for the theory, however with elasticities, both for freight rates and bunker prices, of smaller magnitude than expected. We also find that speed optimizing behaviour is much more pronounced on backhaul trips than on laden trips and that the speed on trips to Japan is almost completely insensitive to changes in freight rates and bunker prices. Our conclusion is that there is a potential for gains from more adoption of slow steaming.

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¹Automated Identification System

²Very Large Crude Oil Carriers

1 Introduction

Most shipping insiders would support the statement by Kontovas (2014)

”...a typical market behaviour in shipping: ships tend to speed up when the market is up, and slow down when the market is down.”

An empirical investigation on the extent to which this widely held view is true is the topic of this paper. Assuming that the maritime transportation industry operates in competitive markets, it can be expected that ship operators optimize their speeds in order to be competitive. More specifically, ship owners are assumed to maximize their profits through choosing a speed that optimally balances the trade-off between freight rate income per time unit and the speed-dependent fuel bill (see for example Wijnolst and Wergeland (1996)).

Considering the recent development of bunker prices and freight rates as the two main economic factors influencing speed decisions, the growing importance of slow steaming comes as no surprise, since high bunker prices, very low freight rates and oversupply of transportation capacity squeeze ship owner’s profits.

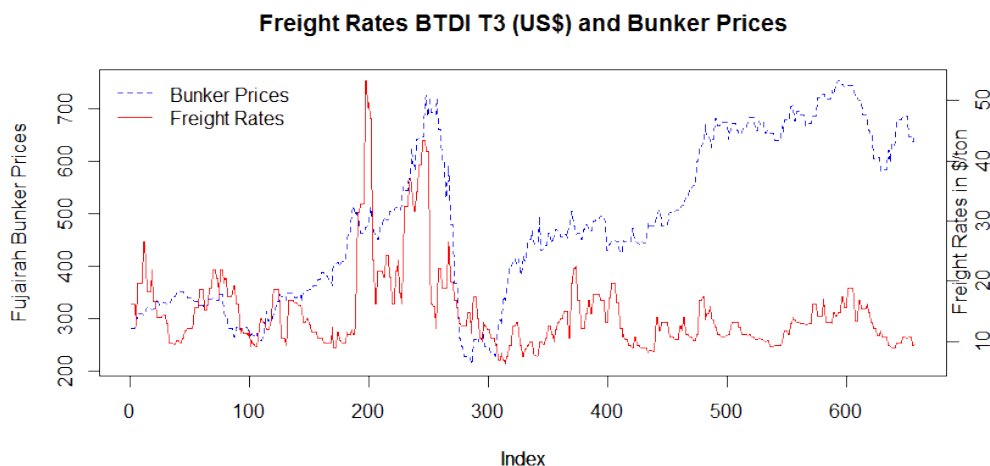


Figure 1: Freight rate and Bunker Prices 2006-2012

Not only economic calculus, but also the increasing relevance of climate change and emission reduction attracts attention to slow steaming. In particular, regulation of CO_2 emissions is expected and has recently

been subject to scientific discussion on optimal environmental taxation, see e.g., Keen et al. (2012). If the purpose of such regulation is to decrease emissions by decreasing the speed of ships, it is essential to understand how sensitive speed behaviour is on changes in underlying determinants such as bunker prices and freight rates.

In contrast to the specialized press, speed optimization has been paid little attention to in the scientific literature. An explicit theory of optimal vessel speed was formulated by Ronen (1982) and Alderton (1981). Otherwise theoretical concepts of optimal vessel speed have been used implicitly modeling transport supply capacities, see, e.g., Norman and Wergeland (1979), Beenstock and Vergottis (1993) or papers within the OR/MS literature dealing with routing and scheduling applications, e.g., Christiansen et al. (2007), Perakis and Bremer (1992), Varelas et al. (2013) among others. Most recently Psaraftis and Kontovas (2013) and Kontovas (2014) have reviewed existing vessel speed models (implicitly and explicitly) and furthermore amended them with generally known but formally new speed determinants such as inventory costs and payload. A common assumption in the literature is that fuel consumption is approximately proportional to the cube of speed. As far as we know, there is only one empirical study, by Jonkeren et al. (2012), that analyzes if actual speed optimization is done according to what economic theory predicts. That study is made on inland waterway carriers and concludes that freight prices have a positive impact on speeds and that fuel prices have a negative impact. In the present paper, we study this issue for Very Large Crude Oil Carriers (VLCCs). The reason for choosing this market segment for our study is threefold. Firstly, according to Asariotis et al. (2011), transport by VLCCs constitute 44% of all oil tanker trade, which in turn constitutes one third of all seaborne trade. Both seen from a business and from an emissions perspective, the VLCC market is therefore of great importance. Secondly, the fleet of VLCC tankers are considered to be homogenous in the sense that there are no dramatic differences in the characteristics of the ships. Differences in speeds are therefore less likely to be due to differences in unobserved ship characteristics. Thirdly, the AIS (Automated Identification System) trip data that we use does not include the loading and unloading times and consequently gives a more accurate measure of the average speed than what is possible from the dataset used in Jonkeren et al. (2012) Utilizing an extensive data set covering all VLCC trips leaving from the Persian Gulf heading towards Japan, South Korea, and China³ between 2006

³Our data set also covers all observed trips westwards from the Persian Gulf to the US gulf and Europe. Since we have no information on their routing(if they partly unload or ballast through Suez), we do not include those in our analysis. Because

and September 2012, we analyze observed speeds and use a regression analysis on the relationship between vessel speeds, freight rates and bunker prices and discuss the unexpected outcomes.

The remainder of the paper is structured as follows: The next section presents the version of the theoretical model by Ronen (1982) that we base our study on. Section 3 give details and an initial descriptive analysis of the data used. In Section 4 the empirical results are given and Section 5 discusses explores avenues for further research in the context of our findings. Section 6 concludes.

2 Methods

2.1 When do ships sail slow?- A theoretical model

Since we want to evaluate the underlying rationale for the speed decision in practice we start out with introducing a simple speed optimization model for bulk carriers. The following model is based on Ronen (1982) and takes a profit maximizing view of a ship owner chartering out his ship on the spot market. In the spot market the ship owner receives a route- and direction specific freight rate in dollar per ton of cargo transported from port A to B. Let this freight rate received per ton of shipped cargo be denoted by R and the amount of cargo to be transported by W . A transport leg of length D is completed in d days at the speed V which is bounded below by some minimum V_{min} which the vessel has to maintain in order to be able to manoeuvre and above by V_{max} . It is assumed that fuel costs, which are the product of daily fuel consumption F and bunker cost of the fuel C_B are to be the only cost factor, due to the assumption that fixed cost to operate the ship are relatively small and do not change with speed. In this basic model it is furthermore assumed that the shipowner does not own the cargo and hence does not include any depreciation for the value of the cargo.

The daily fuel consumption depends on the vessels speed in the following, commonly acknowledged way (for a more detailed description see Appendix), where ε is typically between 2.6 and 3 for VLCCs:

$$F = \left(\frac{V}{V_d}\right)^\varepsilon F_d \left(\frac{\nabla}{\nabla_d}\right)^{\frac{2}{3}}. \quad (1)$$

these trips only represent 13 % of all observed trips, we are confident that our sample is representative for the VLCC sector.

Table 1: Notation

R - Spot freight rate in dollar/ton transported from A to B.
 W - Weight of cargo which is needed to be transported in tons .
 D - Distance from port A to port B
 d - days it takes the vessel to sail from port A to port B
 V - Vessel speed
 V_{min} - Minimum vessel speed
 V_{max} - Maximum vessel speed
 F - Daily Fuel Consumption
 F_d - Fuel consumption at design speed V_d
 P_B - Price of Bunker fuel in Dollar/ton.
 ε - Fuel consumption exponent (depends on vessel type, for VLCCs usually between 2.6-3.0)
 ∇ - Displacement of a ship
 ∇_d - Displacement at design draught
 ∇_B - Displacement in ballast
 ∇_L - Displacement laden

Then, daily profit can be written

$$\frac{\pi}{d} = \underbrace{\frac{RW}{D}}_{\text{Daily freight income}} - \underbrace{P_B \left(\frac{V}{V_d}\right)^\varepsilon F_d \left(\frac{\nabla}{\nabla_d}\right)^{\frac{2}{3}}}_{\text{Daily fuel costs}}. \quad (2)$$

Hence, the speed optimizing daily profit for a laden trip is obtained by

$$\frac{\partial \pi}{\partial V} = \frac{24RW}{D} - \varepsilon P_B F_d \left(\frac{\nabla}{\nabla_d}\right)^{\frac{2}{3}} \left(\frac{V}{V_d}\right)^{\varepsilon-1} \frac{1}{V_d} = 0 \quad (3)$$

s.t. $V_{min} \leq V \leq V_{max}$.

resulting in

$$V_L^* = \left(\frac{24RWV_d^\varepsilon}{\varepsilon P_B D F_d \left(\frac{\nabla_L}{\nabla_d}\right)^{\frac{2}{3}}} \right)^{\frac{1}{\varepsilon-1}} \quad (4)$$

where V_L^* indicates optimal speed in a laden condition. Similarly, the optimal speed in a ballast condition,

V_B^* , is given by

$$V_B^* = \left(\frac{24RWV_d^\varepsilon}{\varepsilon P_B D F_d \left(\frac{\nabla_B}{\nabla_d} \right)^{\frac{2}{3}}} \right)^{\frac{1}{\varepsilon-1}} \quad (5)$$

Since displacement of a laden vessel is greater than displacement of a vessel in ballast ($\nabla_L > \nabla_B$), it follows that

$$V_L^* < V_B^* \quad (6)$$

The profit maximizing speed V^* is increasing in revenue per ton R , weight transported W and design speed V_d and formally decreasing in trip length D (caused by the transformation to daily profits), bunker cost P_B and fuel consumption at design speed F_d . Under this optimal behaviour the elasticities for freight rates and bunker prices would be $\frac{1}{\varepsilon-1}$ and $-\frac{1}{\varepsilon-1}$, respectively. Given a value of $\varepsilon = 3$, which is approximately what the industry assumes, these elasticities would be $\frac{1}{2}$ and $-\frac{1}{2}$.

One factor that is not accounted for here, are the demurrage and dispatch fees agreed upon in the charter party. But since those fees are relatively small amounts and the expected travel time at the date of the fixture should include the hindsight of choosing an optimal speed, those fees are not included in this basic model and are considered as an adaptive measure to unforeseeable events. Note furthermore, that in this basic model it is assumed that freight rates are deterministic, exogenous and additionally that - no matter what speed a vessel sails- it always gets a next cargo at the deterministic freight rate.

2.2 Empirical hypotheses and model selection

In order to specify a model and its functional form for the empirical analysis, the theoretical optimal speed model from above is used. The relationship that is to be tested is how optimal vessel speeds respond to changes in the explanatory variables given from the theoretically optimal vessel relationship. The hypotheses for the coefficient signs evolve from the partial derivatives of the variables determining optimal speed. The optimal speed expressions in equations (4) and (5) are results from economic theory (optimizing behaviour) and a basis for hypotheses about a causal relationship between market conditions and speed decisions. Other, non-measurable speed determining elements, such as weather conditions, currents and port conditions, have to be kept in mind when analysing the results.

For the empirical model we introduce an error term which accounts for the deviation from the optimal relationship and the observed relationship. This is done by multiplying the theoretical optimal speed by an error term μ where $\mu = e^\epsilon$.

$$V^* = \left(\frac{24RWV_d^\epsilon}{\epsilon P_B D F_d} \right)^{\frac{1}{\epsilon-1}} e^\epsilon \quad (7)$$

It is convenient to transform this equation into a log-linear relationship in order to make use of linear estimation techniques, and furthermore simplify it to the following expression:

$$\ln V = \alpha_0 + \beta_1 \ln(R/D) + \beta_2 \ln W + \beta_3 \ln V_d + \beta_4 \ln P_B + \beta_5 \ln F_d + \epsilon \quad (8)$$

where α_0 is the intercept term and the β 's are the coefficients which should represent the influence of the explanatory variables on the dependent variable. Because the spot freight rate is a measure per ton transported on a certain distance the dollar per ton measure of the freight rate is divided by the respective distance to normalize over all routes. Thus, we get a standardized rate per unit of transportation work, i.e. dollar per ton-mile. In the following, this distance-corrected measure is what we mean when using the term *freight rate*.⁴

Our interest is in the regression coefficients from this model specification are significant and furthermore if they have the right sign and magnitude according to the theory. As mentioned in Section 2.1, this would, imply that e.g. β_1 and β_4 would be $\frac{1}{2}$ and $-\frac{1}{2}$, respectively.

Due to lack of information on the actual carried cargo tonnage if the vessel is laden, the variable W is not included as explanatory variable, i.e. it has to be assumed that the vessels are fully laden⁵. This could lead to an omitted variable bias if the vessels are laden to varying extents. A less than fully laden vessel would probably only occur when freight rates are low. On the one hand, this implies that they are less inclined to speed up to earn on high freight rates. On the other hand, less laden vessels have the option to speed up with less fuel consumption compared to fully laden vessels. Therefore it is hard to ascertain in which

⁴In practice also specific port costs might play a role on specific routes, but since the port costs reflect a relatively small share we think that correcting for distance should be sufficient in order to filter out market momentum affecting the freight rate

⁵According to industry experts, vessels are usually fully or almost fully laden

direction a bias of partly loaded vessels would go. Since there is also no information on the design speed and consequently the respective fuel consumption at design speed of the particular ships in the sample, also these two variables have to be excluded as explanatory variables from the empirical model. But since the ships have very similar characteristics (see for example Ådland and Strandenes (2007)), those variables should not have significant influence on speeds and the ratio of those variables could then be treated as a constant. Thus, the baseline model that we estimate has the following form:

$$\ln V = \alpha_0 + \beta_1 \ln(R/D) + \beta_4 \ln P_B + \epsilon \quad (9)$$

As suggested by this empirical model the logs of the observed speeds are regressed on the logs of freight rates, bunker prices using ordinary least squares (OLS). The hypotheses induced from economic theory are that the log bunker price coefficient β_4 is negative and that the log of the freight rate coefficient β_1 is positive.

3 Data

The data and information on VLCC vessel speeds is obtained from IHS Fairplay and AISLive⁶, an international information service company which is able to provide past geographic vessel position data from AIS (Automatic Identification System). For the main VLCC routes departing from the Persian Gulf (to Japan, China, South Korea), single vessel's departure and arrival dates were extracted from January 2006 to September 2012⁷. The trip time was given in hours needed per trip, i.e. arrival time when anchoring minus departure time at the loading terminal. The corresponding average speeds were recalculated using distance tables from AXSmarine⁸ and reported at the time the trips started. In total, the dataset includes 397 different vessels with similar characteristics operating on the 62 routes. The data was provided in form of a very unbalanced panel, i.e. speed observations of 1250 trips along the 62 routes from and to the

⁶compiled by Maritime Insight:<http://maritime-insight.com/>

⁷The original data set includes also major routes from the Persian Gulf to western destinations (US Gulf and Europe), but due to missing information on their routing (via Suez or not), we excluded those trips. The western trips made up for a share of 13 percent of all observations.

⁸available at : <http://www.axsmarine.com/distance/>

Persian Gulf were observed over time, but in very irregular time intervals and highly varying frequencies.⁹ Similarly, a large share of vessels has been observed only once, and the most frequently observed ships up to 16 times. An example of a vessel movement history is depicted in Figure 2 below: The freight rate data

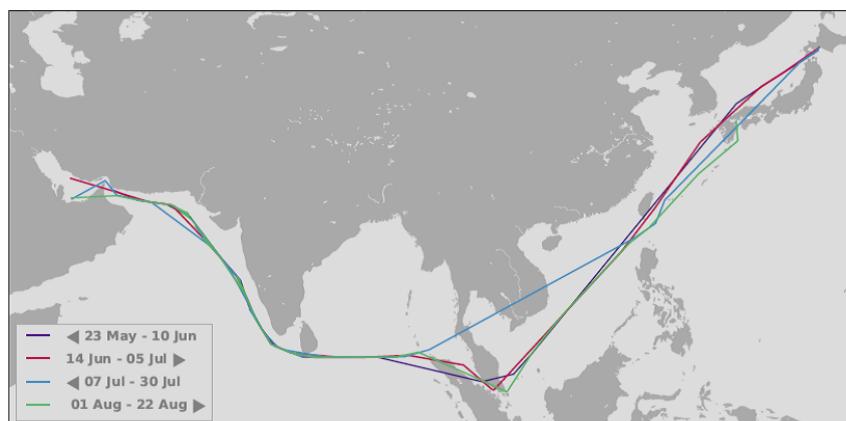


Figure 2: Exemplary vessel movement from the data set

is obtained from the Clarkson Shipping Intelligence Network (2012), one of the world’s leading providers of shipping information services. For the spot freight rate, Baltic Index data for the characteristic routes (Persian Gulf - Chiba (TD3)¹⁰, LOOP (TD1), Ulsan and Rotterdam) is collected on a daily basis reported in World Scale (January 2006 until September 2012). Based on a publication of historic flatrates from McQuilling Services McQuilling Services (2011), Worldscale spot freight rate data was recalculated to US\$ per ton transported on the respective routes. Data on bunker prices is also obtained from the Clarkson Shipping Intelligence Network database. Here weekly Fujairah 380bst bunker prices are used since they are the geographically closest price available for most of the routes, and furthermore the cheapest price available if the shipowner has to choose between destination and departure port to fill up his tanks. Since we do not use the corresponding fixture freight rate data of the single observed ships, but the characteristic market index freight rate data, single speeds do not affect freight rates. Furthermore, we assume the ship owner to be a price taker and the market to be competitive. Hence, we do not think that they strategically collaborate to withhold capacity through slow steaming and that we can therefore safely assume that single

⁹Some routes were observed once (Kinwan), the most frequent route was observed 145 times (Mizushima).

¹⁰called BDTI TD3 (Baltic Dirty Tanker Index TD3) in SIN

ship owners do not affect freight rates on an overall market level.

A way of describing the data in the context of our problem is to compare the empirical averages of speeds for different market conditions, i.e. combinations of freight rates and bunker prices. Freight rates and bunker prices were plotted against each other and the squares indicate the pairwise combination of high, medium and low freight rates and bunker prices. The plot is displayed in Figure 3 in Appendix. The upper left square indicates for example that the freight rate observation is in the highest third of the observed freight rate range, and in the lowest third of the observed bunker prices.¹¹ As one can see especially in the upper left square, the combination of high freight rates and low bunker prices could not be observed in the time period under review. The numbers represent the means of the observations made during each of the nine bunker-freight combinations.

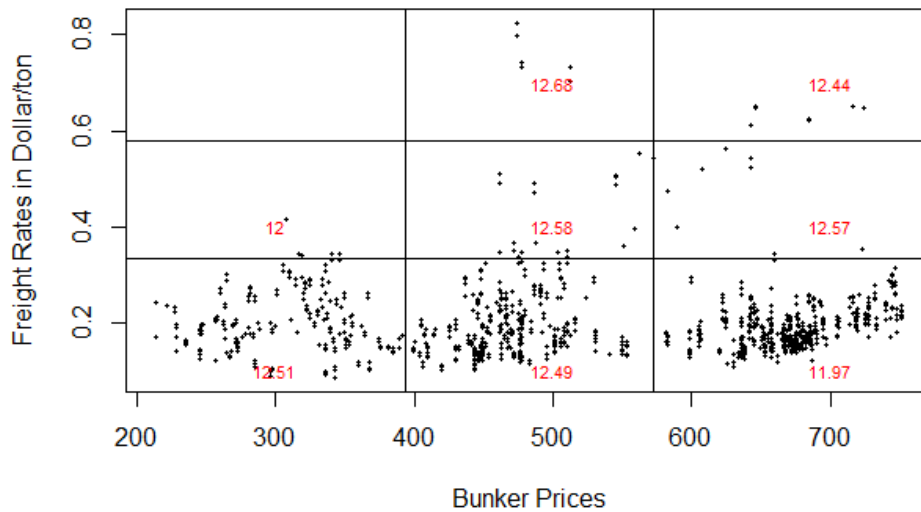


Figure 3: Comparison of mean speeds during different market conditions

¹¹The thirds were defined by the observed range of the variable during the period 2006-2012 and divided by three.

4 Results

From the baseline regression, specification (1), that follows the original model, equation (9), we find that the observed vessel speeds do not respond significantly to changes in freight rates (0.018). An increase in bunker prices however, leads to a slight but significant decrease in speeds (0.060), i.e. a one % increase in bunker prices decreases speeds on average by 0.06%. Because our data set covers trips on different routes and with different directions, we believe that we can differentiate further. According to theory, we have reasons to believe that ballast speeds differ from laden speed. As specified earlier, the fuel consumption function is different for ballasting vessels because they displace less and hence have less resistance. Therefore, as shown in Section 2.1 and Appendix, optimal vessel speeds are higher for ballasting vessels and we expect to observe a difference. Although the AIS data does not indicate the loading condition, it is safe to assume that for the observed trips between the Persian Gulf and Japan, South Korea and China, vessels are laden on the front-haul leg and empty on the back-haul leg (as it is very unlikely that crude oil is transported back to the Persian Gulf). Hence we include a dummy variable for back-haul trips in specification (2). Another difference on the back-haul leg is that vessels in the spot market are typically free from contractual obligations, and ship owners have more freedom to choose their speeds. Therefore we also included interactions between the back-haul dummy and freight rate and the back-haul dummy and bunker price in specification (2). The coefficients indicate that on back-haul trips vessels sail on average significantly faster which is in line with a different fuel consumption curve. Furthermore we see that vessels on the back-haul leg are more responsive to freight rate changes. The responsiveness to bunker price movements, however, is not significantly different from laden trips.

We also choose to test if the trade to Japan differs from the other trade routes. The reason is that we suspect a structural difference for the Japan trade compared to the other major trade routes that we observe. All crude oil that Japan needs is imported via sea, and as much as possible with the cheapest transport mode, which is by VLCC's. Therefore we suspect that a large share of the VLCC trade to Japan is organized through fixed agreements, where the scheduling is more important than transport costs. Hence the flexibility in the contracts can be expected to be limited. It could also be expected that oil majors operate a large number of trips on their own and that there is a high share of time charter fixtures. In

theory this should not have an effect on optimal speed (e.g, Devanney, 2009; Psaraftis and Kontovas, 2013). However, given that we expect the trade to be less flexible in terms of arrival time, those agreements leave less freedom to the shipowner, who is probably most interested in choosing an optimal speed. As an example, for the spot fixture data from Clarksons, we see that only 3% of all available registered fixtures are directed towards Japan, whereas in our observed data, over 50% are trips to Japan. That can be interpreted as an indicator of the fact that most of the VLCC trade to Japan is operated through the fleet of oil majors or time charter agreements. In order to investigate this, we include a dummy for trips to Japan. We also allow this dummy to interact with the explanatory variables. Lacking theory based arguments for singling Japan out we also included a South Korea dummy leaving China as the reference country. Albeit a crude division of the destinations, by using these three countries, we control for region specific effects in a parsimonious way. This regression confirmed the previous result about the difference between loaded and ballast trips.

Table 2: Speed elasticities

	Loaded	Ballast
Freight rate	0.004	0.166
Bunker price	-0.114	-0.184

Summarizing our main results, which are obtained through model specification (3) in Table 3, we find that laden vessels do not respond to changes in freight rates. A one % increase in bunker prices, on the other hand, reduces speeds with 0.11 %. On back-haul trips, vessels respond to changes in freight rates ($0.004+0.162=0.166$) and to changes in bunker prices ($-0.114-0.070=-0.184$). These results are summarized in Table 2. For trips towards Japan, none of those effects are found. For both freight rates and bunker prices coefficients are close to zero and insignificant (fr: $0.004-0.020=0.016$ and bp: $-0.114+0.123=0.009$). In general, the results only partly support our hypothesis that vessel speeds respond to changing market conditions.¹² Interpreting the intercepts, back-haul trips are significantly faster on average (0.782).

Strictly speaking, the data is on a panel form, a cross-section of ships observed over time. However, since many of the ships are observed only once, a panel model approach is not feasible. In addition, both our explanatory variables, freight rates and bunker prices are market prices and the same for all ships at a particular point in time.

¹²We estimated also a model including distance as a regressor with a significant positive coefficient. Other coefficients are robust to the inclusion of distance however.

Table 3: Regression Results

	<i>Dependent variable:</i>		
	Ispeed		
	(1)	(2)	(3)
lfrcorrect	0.018 (0.012)	0.022 (0.013)	0.004 (0.029)
BackhaulD		0.588** (0.285)	0.782*** (0.286)
JAPD			-0.709*** (0.196)
lbunker	-0.060*** (0.013)	-0.062*** (0.014)	-0.114*** (0.025)
lfrcorrect:BackhaulD		0.096** (0.044)	0.162*** (0.044)
lfrcorrect:JAPD			-0.020 (0.031)
BackhaulD:lbunker		-0.060 (0.040)	-0.070* (0.040)
JAPD:lbunker			0.123*** (0.028)
Constant	2.898*** (0.083)	2.914*** (0.089)	3.158*** (0.177)
Observations	1,250	1,250	1,250
R ²	0.018	0.032	0.144
Adjusted R ²	0.017	0.028	0.139
Residual Std. Error	0.140 (df = 1247)	0.140 (df = 1244)	0.131 (df = 1241)
F Statistic	11.665*** (df = 2; 1247)	8.300*** (df = 5; 1244)	26.158*** (df = 8; 1241)

Note:

(1) follows equation 9

(2) $\ln V = \alpha_0 + \beta_1 \left(\frac{R}{D}\right) + \beta_2 \text{BackhaulD} + \beta_3 P_B + \beta_4 \ln \frac{R}{D} * \text{BackhaulD} + \beta_5 \ln P_B * \text{BackhaulD} + \epsilon$

(3) $\ln V = \alpha_0 + \beta_1 \left(\frac{R}{D}\right) + \beta_2 \text{BackhaulD} + JAPD + \beta_3 P_B + \beta_4 \ln \frac{R}{D} * \text{BackhaulD} + \beta_5 \ln \frac{R}{D} * JAPD + \beta_6 \ln P_B * \text{BackhaulD} + \beta_7 \ln P_B * JAPD + \epsilon$

*p<0.1; **p<0.05; ***p<0.01

Concluding the results, it can be said that VLCC vessel speeds on most of the analysed routes respond to freight rates and bunker prices but not to the extent that Ronen's theory would predict. Depending on the choice of ε , the elasticities implied by this theory would be approximately 0.5 and -0.5 for freight rates and bunker prices, respectively. Our estimates are 0.004 and -0.11 , respectively, for non-Japan trade and close to zero for Japan trade. Compared to front haul trips, return trips to the gulf exhibit higher elasticity with respect to relative freight rate and bunker price movements (0.17 and -0.18). Furthermore, for the AG-Japan trade we do not find evidence at all that speeds respond to changes in freight rates and bunker prices.

5 Discussion

In this paper we give empirical evidence for vessel speed responses to changes in market conditions in the VLCC market. Our results support the theory and what is claimed to be a general practise in the maritime industry, but only partly. There are several possible reasons for this. One criticism of the model is that the value of the cargo is not included as a main determinant. Theoretical suggestions to include the cargo value in the model exist, but would change the objective towards maximizing not only ship owners, but also the cargo owners profits. A high oil price would theoretically mean that one would, on the one hand, like to speed up because of a reduced loss in cargo value but, on the other hand, slow down since fuel is expensive. Although it would be interesting to investigate this issue empirically it will involve the difficulty of separating the effects of cargo value and bunker prices, which for VLCCs can be expected to be highly correlated. Besides the problematic issue of separating cargo value and fuel cost, another factor comes into play here. If cargo value and inventory cost should be considered as speed-increasing variables, it is worth investigating the storage situation for crude oil at destination at the same time. If cargo cannot be sold and used immediately, it has to be stored at destination. If storage is expensive, it pays out to sail slower, taking the view of a cargo owner. Consequently cargo owners do not necessarily push ship operators to sail faster, even if they have relatively high bargaining power. On the contrary, it could occur that ship operators are asked to sail even slower given low freight rates. Under these circumstances it is known that cargo owners even hire VLCCs as storage. Since information on the storage situation is hard to obtain systematically

at this time, it is also left for future research to analyze its influence on speed. Summing up the concerns about not including inventory costs in the empirical analysis for the VLCC market, we think that it might be a factor to be considered when modelling the speed choice. For the empirical analysis however, we think that we can be confident about having identified the market conditions as the main systematic drivers that should provide a clear a priori guidance on vessel speeds behaviour. Besides considering cargo value, other hypotheses that explain other potential systematic influence on vessel speeds can be formulated. An argument that is brought forward when talking to the industry is that demurrage and dispatch fees actually play a decisive role when deciding about vessel speeds. From a short term perspective, that seems to be a logical and a rational effect, but in the long-term one could expect that those contractual features can be modified in a way that captures possible gains from fuel savings. More specifically, if the actual savings from slow steaming outweigh benefits from increased income caused by increased speeds, it could be expected that shipowners and cargo owners share the savings and are both better off. Maybe it would be an option to further improve contract designs first, such that the win-win situation that slow steaming can generate during low markets can actually be realized, before introducing new regulation aiming at speed reduction. Similarly, berthing policies, such as first-come-first-serve policies that encourage vessels to speed up also reflect the rigid contractual legal framework, which hampers emission reduction that could be achieved by simple measures (Alvarez et al., 2010). Increased knowledge about vessel speeds response to changing market conditions is not only informative for the design of environmental regulation in shipping, but it also has implications for short term supply. Speed changes of the active fleet can be considered to be the most important measure to adjust the supply side on a short term horizon, and are therefore relevant to all market participants.

6 Conclusion

We have empirically analyzed the responsiveness of vessel speeds to changes in market conditions, specifically freight rates and bunker prices, based on a normative speed optimization model. We find that there is a systematic response in vessel speeds, given our data on the VLCC speeds between 2006 and 2012 from the Persian Gulf to major destinations in Japan, South Korea and China, but that it is firstly smaller than

theory would suggest and secondly for freight rates not significant on laden trips. For the Japan-AG trips, we even find that the effect on speed of both freight rates and bunker prices are insignificant. For freight rates we find that the effect on speed is more pronounced and significant on backhaul trips. Concerning the deviation between theory and our results we discuss different possibilities which would be important to investigate further. One is that cargo owners might resist slow steaming when bunker prices are high since then the capital bound in the value of the cargo makes delivery more urgent. Others are that demurrage and dispatch fees play an important role and that some ships are operating under contractual obligations disabling significant variation in speed.

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Appendix

Given a certain hull design, i.e. a specific vessel (design for a certain service(speed)), the admiralty coefficient defines an approximate relationship between the propulsion power, ship speed and displacement (MAN Diesel & Turbo, 2011).

The admiralty coefficient is characterized below, where propulsion power is denoted by P , displacement by ∇ and speed by V .

$$A = \frac{\nabla^{\frac{2}{3}} V^3}{P} \quad (10)$$

The admiralty coefficient should be the same for any speed, displacement and power specification for one vessel. Thus,

$$A = \frac{\nabla^{\frac{2}{3}} V^3}{P} = \frac{\nabla_d^{\frac{2}{3}} V_d^3}{P_d} \quad (11)$$

where the index d indicates design characteristic that are known. Therefore the power needed for a certain speed can be specified as:

$$P = \frac{\nabla^{\frac{2}{3}} V^3 P_d}{\nabla_d^{\frac{2}{3}} V_d^3} = \frac{\nabla^{\frac{2}{3}}}{\nabla_d^{\frac{2}{3}}} \left(\frac{V}{V_d} \right)^3 P_d \quad (12)$$

Thus the displacement ratio scales the speed-power relationship. Assuming that the relationship between effective power and fuel consumption is proportional for any given constant speed, the relationship between speed and fuel consumption is scaled in an equivalent way by the displacement ratio. Daily fuel consumption as a function of a constant speed and displacement (displacement is correlated with draught and wetted surface) can then be formulated as:

$$F(V, \nabla) = \frac{\nabla^{\frac{2}{3}}}{\nabla_d^{\frac{2}{3}}} \left(\frac{V}{V_d} \right)^3 F_d \quad (13)$$

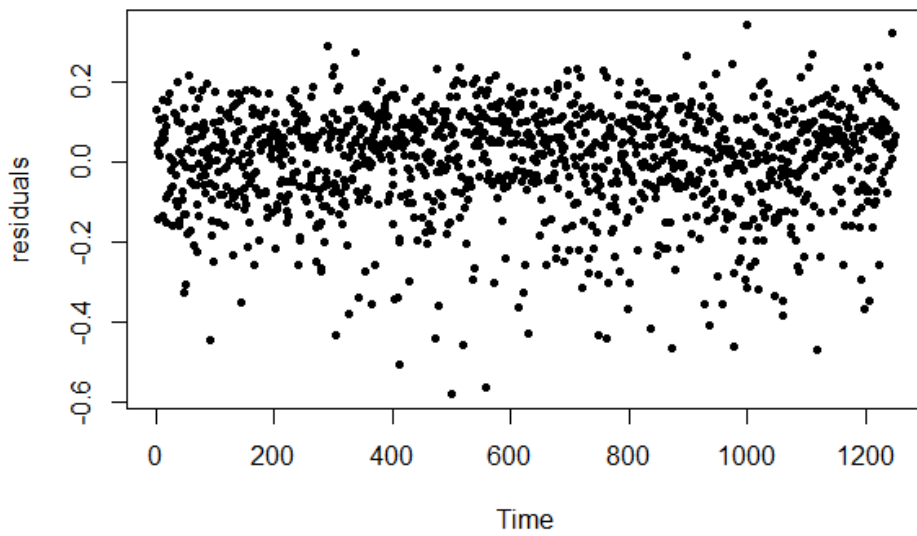


Figure 4: Residuals specification 3

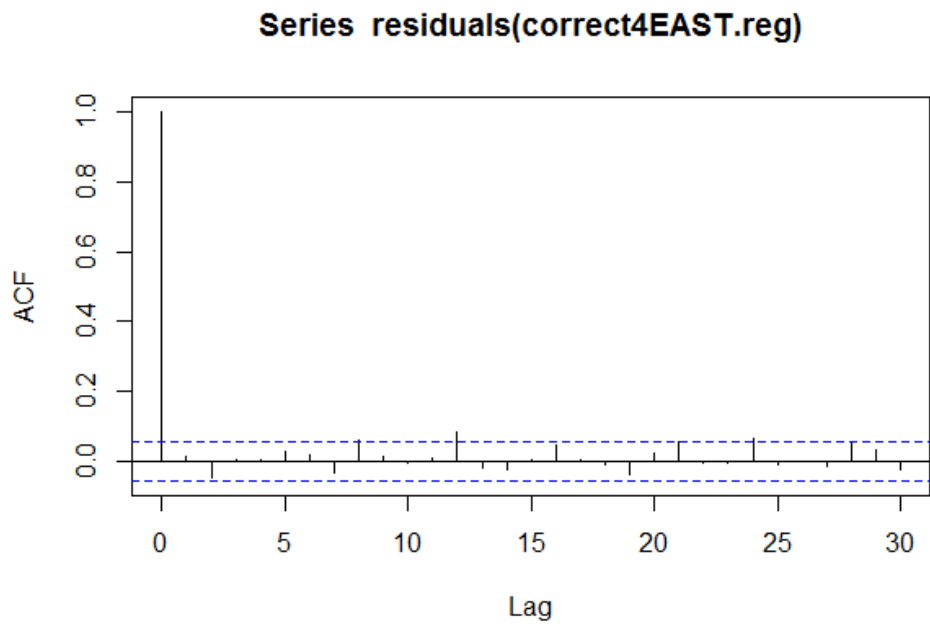


Figure 5: ACF residuals for specification 3

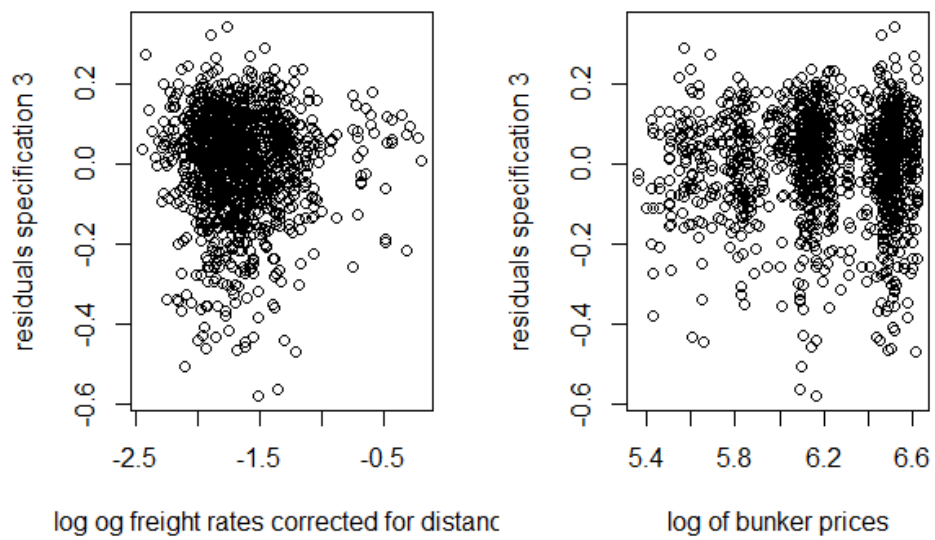


Figure 6: Heteroskedasticity inspection plot